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WARMTH AND COOLNESS OF COLORS

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The literature in general favors the view that red and yellow suggest warmth while green and blue seem cool (6-10, 13, 16, 17, 19); and in essential agreement with this tradition are the results of the present study. This study was originally stimulated by a question to the writer from an illustrating artist. He remarked that he and others feel that blue is a cool hue but that they wanted to know which blue is coolest. "Is it greenish-blue or turquoise; is it normal or true blue; or is it a somewhat purplish blue?" Emphasis on specific hue, as distinguished from related hues, is important not merely because there are so many hues, but because of lack of close hue control in past investigations of the thermal problem. Studies in which only a few hue samples are used cannot disclose relative warmth and coolness in more than a crude way.

Four conceivable varieties of warmth and coolness of color include: (1) emotional warmth or coolness in the limited sense that the color merely appears that way visually; (2) 'real' emotionality in the sense that the color actually evokes an affective response in the person viewing it (3, 4). Thus, one might ask himself, "Does this particular magenta merely look emotionally warm or does it really arouse me emotionally?" (3) Similarly, the color might be 'really' thermal, that is, make a surface identified with it feel warmer or cooler to the touch (13), or (4) the color might yield a thermal suggestion visually, that is, it might merely appear thermally warm or cool. Again, one could ask himself, "Does this red actually feel warm to my hand or does it simply look warm?" The last variety is the present concern.

Our purpose was twofold, i.e., to secure estimates of this apparent warmth and coolness from numerous closely stepped samples, and if possible, to secure evidence testing an hypothesis which has long been favored implicitly. That is the view that the apparent

warmth and coolness are due to hue association with chromatic thermal objects. Thus, we might not only answer the artist's factual question but also confirm the reason for the relation.

Estimates of Apparent Warmth and Coolness

Each observer individually inspected a chart of the fifty surface color samples known as the Munsell "Maxima." This series presents smooth graduations of lightness and saturation, and approximately equal steps of hue, adjacent samples differing in hue perceptibly but not markedly. This emphasis on hue, as distinguished from saturation and lightness, has been justified by the demonstration that hue is much more important than those other attributes in the determination of the apparent warmth or coolness of color (16 p. 457-8; 17 p. 183). Furthermore, the Munsell "Maxima" are believed to be more generally representative of the colors of everyday life than any other single hue series of available pigments. The specifications are presented in Table I in terms of the hue notation of the Munsell system and the colorimetric dimensions of dominant wave-length λ, excitation purity P, and reflectance relative to magnesium oxide ρ, (2, 5).

The samples themselves were approximately two inches by one-half inch in size and somewhat wedge-shaped. They were mounted about one-sixteenth of an inch apart in the form of a closed ring which was two inches wide and eleven and one-half inches in external diameter. The light neutral ground supporting the samples had a daylight reflectance of 0.65 and a width of 20 inches. The subject made observations while holding the chart in his hands at reading distance or while viewing it hanging on a wall. The instructions called for a decision concerning which color suggested the greatest impression of thermal warmth, *viz.*, seemed warmest, and which color appeared coolest.

The principal data are graphically exhibited in Figure 1 in terms of frequencies of judgments of 'warmest' and 'coolest' as functions of Munsell hue. The height of any ordinate represents the number of subjects who judged the corresponding color to be 'warmest' (dots) or 'coolest' (circles).

The 'warmest' judgments show a minor mode in the violet at 420 mμ, but the break in the ordinate-scale reveals how striking is the major mode at 610 mμ or 5R. It may be remarked here that

TABLE I

Frequencies of Judgments of 'Warmest' and 'Coolest' by 297 Subjects in the Munsell "Maxima" Hue Series of 50 Chromatic Samples. Columns to the left present the specification of each sample in terms of Munsell hue, H, dominant wave-length, λ, excitation purity, P, and reflectance relative to magnesium oxide, ρ. (2) Columns to the right contain the results for males (M), females (F), whites (W), and negroes (N).

Serial	Munsell	I C I			Warmest		Coolest		Warmest		Coolest		Warmest	Coolest
No.	Hue, H	λ	P	ρ	M	F	M	F	W	N	W	N	Total	Total
1	1	493c	34	20	2	3			5				5	
2	3	629	37	21	6	5			11				11	
3	5 R	610	48	21	53	28			47	33			80	
4	7	602	59	25	18	18			26	12			38	
5	9	597	66	29	16	10	1		16	10	1		26	1
6	1	593	72	32	7	10			8	9			17	
7	3	590	81	33	22	5			14	13			27	
8	5 YR	587	80	35	4					4			4	
9	7	584	80	36										
10	9	582	82	39	1	1			1	1			2	
11	1	580	83	45	3					3			3	
12	3	578	83	52	14	2	6	4	11	4	6	4	15	10
13	5 Y	576	80	53	4	2	4	3	3	3	5	2	6	7
14	7	574	80	49			7	4		1	6	5	1	11
15	9	573	78	49			4	7			8	3		11
16	1	572	76	46			13	6			9	9		18
17	3	570	72	43	1		3	7			7	4		11
18	5 GY	567	70	42			9	6		1	9	6	1	15
19	7	566	62	36	1		6	1			5	2		7
20	9	561	53	32			9	7		1	9	7	1	16
21	1	552	42	28			15	10			21	4		25
22	3	538	28	23			12	9			15	6		21

Serial No.	Munsell Hue, H	ICI λ	ICI P	ICI ρ	Warmest M	Warmest F	Coolest M	Coolest F	Warmest W	Warmest N	Coolest W	Coolest N	Warmest Total	Coolest Total
20	9	561	53	32			9	7		1	9	7	1	16
21	1	552	42	28			15	10			21	4		25
22	3	538	28	23			12	9			15	6		21
23	5 G	513	19	20			2	2			2	4		11
24	7	503	21	19			3				3			3
25	9	500	23	19			1				1			1
26	1	497	25	20			2	1			2	3		5
27	3	494	28	20			4	2			5	1		6
28	5 BG	492	32	19			5	3			5	3		8
29	7	490	35	17			5	3			6	2		8
30	9	489	37	15			4	2			6			6
31	1	488	40	14			6	1			5	2		7
32	3	485	46	13			4	3			5	2		7
33	5 B	483	51	12			7	2			5	4		9
34	7	482	54	11			2	3			2	3		5
35	9	481	57	9	1	2	6	2	1		5	3	1	8
36	1	480	58	9		1	5	5			4	6		10
37	3	478	60	9		5	2	3	2		3	2	2	5
38	5 PB	476	62	8	2	5	15	7	3		15	7	3	22
39	7	470	58	9	1	6	6	1	2	4	5	2	6	7
40	9	460	53	9	6	2	4	1	10		3	2	10	5
41	1	420	47	10	4		7	1	8	3	2	6	11	8
42	3	563c	46	12	5				4				4	
43	5 P	560c	48	13	2				3				3	
44	7	556c	46	14	2		1	1	1	1		1	2	1
45	9	547c	45	15		1			1		1		1	1
46	1	533c	41	16	1	1			2	2			4	
47	3	510c	36	19	2		1	1		1			1	
48	5 RP	502c	36	19	2	1			2				2	
49	7	497c	35	19	1	3			4				4	
50	9	494c	35	19	3	2		1	6			1	6	1

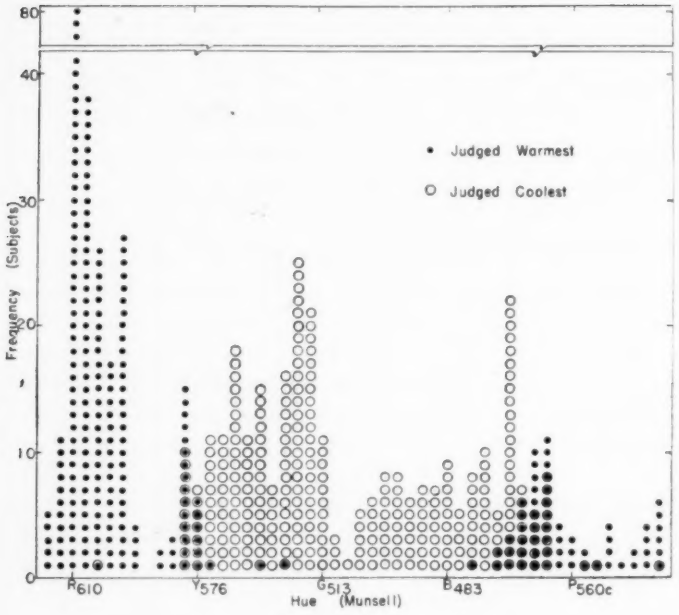

FIGURE 1

Judgments by 297 observers of the 'warmest' and 'coolest' of the 50 Munsell "Maxima" color samples. Each black dot indicates that one subject judged warmest that color represented on the abscissa-scale below. Similarly, each open circle indicates a subjective estimate of coolest. Inscribed dots symbolize overlapping judgments. Dominant wave-lengths corresponding to the principal Munsell hues are shown as subscripts. This figure was plotted from the last two columns of Table I.

when the data from the first 201 cases had been taken, they were scrutinized, and the sharpness of this peak at 610 mμ rendered them suspect. It was believed that the identifying numbers of the samples might have somehow biased the selections. The potency of suggestion in distorting the results of subjective studies of this sort is not to be underestimated (14). Therefore, the samples were completely renumbered, and with this new orientation a control experiment of 96 cases was performed. Since the distribution of the 96 cases evinced close agreement with that of the original 201

cases, the result of the control experiment was regarded as negative, and all data were pooled for the joint presentation in Figure 1.

The 'coolest' colors reveal no such marked mode, but range irregularly from yellow through green and blue to purple. There are, to be sure, some indications of peaking in the yellow around 572 mμ, the green at 552 mμ, and the blue at 476 mμ. In general, however, the judgments of 'coolest' are seen to show much greater variability than those of 'warmest.' If frequency is indicative of intensity or degree, there is no single outstandingly cool hue or narrow range of hues. This relatively great range of cool hues may serve to explain in some measure the artist's difficulty in deciding on a coolest hue.

Table I presents sex and race break-downs of the total cases which were plotted in Figure 1. In the columns to the right of the sample specification, are given the results for 184 males (M) and 113 females (F); and for 191 whites (W) and 106 negroes (N). These data disclose no important sex difference whatever. There is some suggestion of a race difference in the 'warmest' judgments. The negroes evince a tendency to make their 'warmest' judgments in the red to yellow region more frequently than the whites, and in the blue to purple region less frequently than the whites. This minor difference is apparent in both sexes, but it might well prove to be nothing more interesting than a statistical artifact. In general, the frequencies in Table I clearly indicate that the principal relations evident in the data as a whole are persistently manifest in both sexes and both races.

Associational Hypothesis

The relative freedom from overlapping of warmest and coolest judgments, together with the formal similarity of the five sets of frequencies in Table I, indicate that some effective selective agency must be operating. Only two possible forms of explanation occur to the writer. First, the reflective properties of the paper samples might themselves be such as to provide direct stimulation of the temperature sense in the skin as the basis for the differential hue judgments (15). Thus, red might be reported as looking warmer because it felt warmer, in accordance with our hypothetical type 3. This far-fetched form of explanation can be ruled out without test because of the method of presentation of the stimuli; they all

operated simultaneously at a relatively fixed distance from the face. There seems to remain only the associational view that the apparent warmth or coolness is acquired by conditioning or selection in the individual or race, from chromatic objects or processes which are perceptually warm or cool. Some of our data bear upon this hypothesis.

The original group of 201 subjects were asked not only to select the 'warmest' and 'coolest' colors on the chart but to report such reasons for their selections as might occur to them. A great variety of specific objects and conditions were mentioned which were not only chromatic in appearance but which regularly stimulate real thermal perceptions. As an illustrative sample of these stimuli we may mention: the cool green-yellow of iced lemonade and lime drinks, the cool jade green of summer furniture, the cool green of the spring season, the cold blue of pictured ice, cold blue of chilled lips, warm color of a baked brick or a lobster just boiled, warm of a red terra cotta roof in the sunshine, hot like an inferno, hot like the desert sand, like red coals, the cold blue of steel, cool of the gray-green sea, cool of mint, cool as a cucumber, cool like summer out-of-doors colors, cold like the predominating colors of a winter's day, the gray-blue sky of a cold day; the red summer sunset symbolic of a hot day to come. As a rule, natural rather than artificial sources of temperature stimulation appeared to predominate.

Such associated conditions or objects were plotted in relation to hue. The hue assignments were those of the observers and might or might not be correct for the objects. And, of course, the object mentioned by the observer was not necessarily the real reason for his hue selection. The largest classes of objects were, on the warm side, fire or flame, sun, red-hot metal, dark clothing; and on the cool side, water and bodies of water, vegetation, shade and dark, ice and the arctic, light clothing. Perhaps snow would have been included if white had been among the evaluating colors in the hue chart. Figure 2 shows that the distribution of warm and cool objects derived from these reports is very similar in form to the distribution of warm and cool colors in Figure 1.

These data provide some idea of the classes of objects which the observers thought of as warm and cool and the classes of hues with

which they associated those objects. Perhaps it is obvious that the particular object which an observer thinks of may depend upon the thermal judgment which he has just made. Thus, the reason why Figure 2 resembles Figure 1 may be that the observers naturally thought of temperature stimuli which resembled the color samples then seen on the chart. This arousal of the thought of a temperature stimulus by observing a color sample might favor but would not prove a special efficacy in the reverse association. In other words, looking at a 'warm' color sample with the resultant thought of a perceptually warm object of like hue would not prove that a prior association with that object was what generated the apparent warmth of that sample. So, if observers frequently thought of objects of the same hue and thermal valence by association at the moment, the result might be a biased selection of data which would amount to a forcing of the form of Figure 2 to resemble Figure 1.

Two controls have been imposed upon this plausible reason for

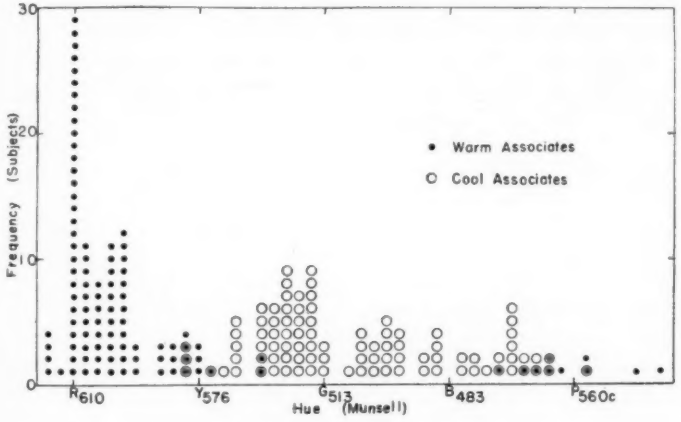

FIGURE 2

Frequencies of reported associations of perceptually warm and cool objects or conditions with the various colors in the 50 Munsell "Maxima" series. Each black dot represents a warm associate and each open circle a cool associate. Inscribed dots symbolize overlapping associates. This figure is based on the reports of the 201 subjects who were asked to give reasons for their thermal estimates.

the close correlation of apparent temperature of samples with perceptual temperatures of objects. The first of these controls consisted in having the sample estimates and the object estimates made at different times. The group of 96 subjects above-mentioned had not been asked to rationalize their 'warmest' and 'coolest' judgments of the chart at the time of making them. But after an interval of four months had elapsed, this group was asked to "think of the warmest and the coolest objects or conditions which you can and write down their names." Even then, no preliminary clue was given that this step would be followed by hue-assignments.

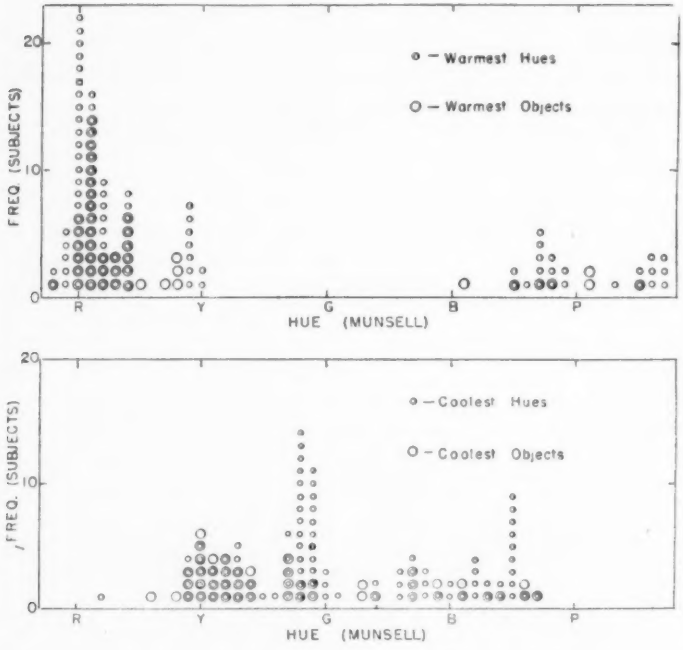

FIGURE 3

The upper chart presents judgments of 'warmest' hues (small circles) and hue-assignments to objects judged warmest after the lapse of four months (large circles). The lower chart shows the results of the analogous 'coolest' judgments.

But shortly after a subject had recorded the names, he was given the sample chart with the request to estimate by reference to it, the hues of his chosen objects. Figure 3 shows the hue distribution of the original apparent temperature judgments of the color samples as compared with the hue distribution of these perceptual temperature judgments secured four months later. The similarity is marked and points to the operation of a common factor. This factor could not be suggestion or association due to close temporal proximity of the recorded sample judgments and object rationalizations.

Still further to eliminate the possible operation of adventitious associations, another form of control was adopted. A new group of subjects were asked to list perceptually warm and cool objects or conditions and to indicate which they considered to be the warmest and which the coolest. This was done without any reference to color whatsoever. Then a second new group of subjects were requested to assign hues to objects thus chosen. The expected result would be representative frequencies of hue estimates of unselected warm and cool objects. If a plot of these data resembled the plot of apparent temperatures in Figure 1 or Figure 3, the resemblance could not be due to suggestions or associations in the minds of a single group of subjects.

The first step was to examine the lists secured from the 34 students of the first new group and make a random selection of stimuli mentioned more than several times. The 56 subjects in the second new group individually evaluated these stimuli for hue by reference to the color sample chart. The plotted results appear in Figure 4.

The distributions of Figure 4 show greater overlapping than before, but their general form agrees with the other results. Incidentally, it may be noted that the minimal shift in the warm mode, *viz.*, from 5R to 7R, is correlated with the appearance of a slight discoloration in sample 5R. These data are reliable; fractionation into first and second halves yields distributions of the same form. They, too, support the view that perceptually thermal objects account for apparently thermal colors.

Discussion

Overlapping Judgments. All data agree in representing the principal regions of overlapping judgments in the Y and PB regions

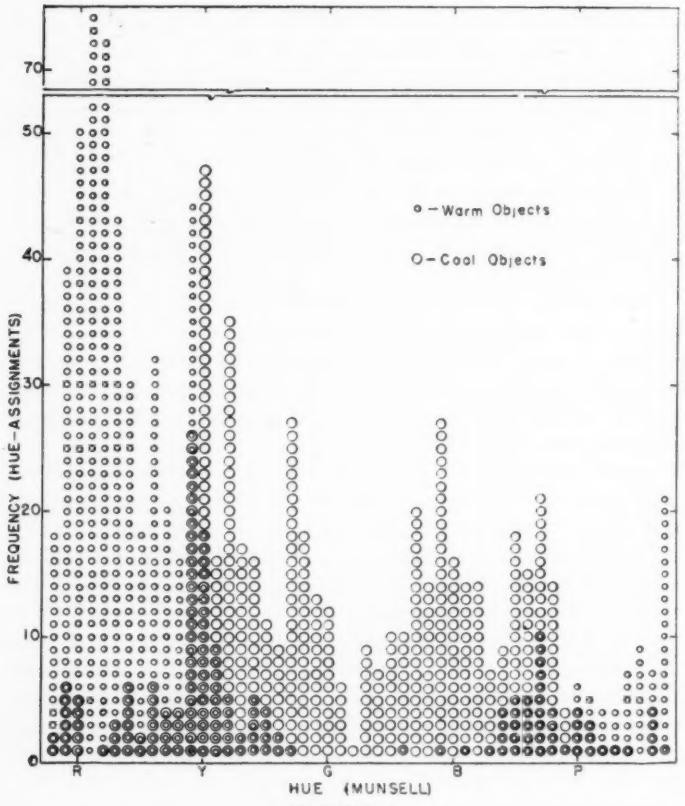

FIGURE 4

Frequencies of 537 hue-assignments by one group of subjects to perceptually warm and cool objects proposed by a different group of subjects.

of the Munsell hue scale. Some of this overlapping is unquestionably due to individual differences in experience with color and in recognitive estimates of it. Lack of precision due to the difficulty of estimation may also account for some of the overlapping. The greatest overlapping (Figure 4) occurred in the last experiment in which many of the selected objects were not definitely

chromatic and were reported difficult to evaluate. Apart from such matters, there is to be considered the more interesting possibility of actual conflicts in some of the color associations.

Clothing colors may be mentioned in this connection. Half a dozen observers in the first group reported that warm or winter clothing is characteristically dark and that the dark colors PB and P, therefore, seem warm. Several others remarked that such colors seem warm because they absorb more radiation. If these dark colors are also associated with the familiar coolness of shade, darkness or night, overlapping and conflict would seem to be inevitable. Such data might help account for the minor mode at 420 mμ in Figure 1. On the other hand, ten observers explicitly noted that cool or summer clothing is typically light in appearance and that light colors, especially yellow and green-yellow, therefore seem cool. Several also remarked that light clothing seems cool because it reflects more light. If many of the common warm associations with objects like yellow flames and the sun conflict with these, some accounting for the overlapping in the Y region is also established. Reference to the data, however (Figures 1 to 3), suggests that probably only the xanthic yellows should be counted as cool.

Range of Coolest Colors. The relatively long range of the 'coolest' colors is evident from Table II. Defining the end-points as the modes of the overlappings, the ranges for all plotted data are presented both in terms of the standard Munsell hue notation and the 100-unit hue-scale. The last column shows what per cent the coolest range is of the complete hue circuit (comprised of the warmest and coolest ranges together).

TABLE II
THE RANGE OF THE 'COOLEST' ESTIMATES AS EXPRESSED IN TERMS OF THE MUNSELL NOTATION AND THE 100-UNIT SCALE

Data		Notation	Scale	% Coolest
Hues	Figure 1	3Y—1P	23—81	58
Hues	Figure 3	3Y—5PB	23—75	52
Objects	Figure 2	3Y—1P	23—81	58
Objects	Figure 3	1Y—9PB	21—79	58
Objects	Figure 4	3Y—9PB	23—79	56

In the case of the last group, Figure 4, the spread for the cool objects remained the greater even though there were only two-thirds as many cold objects to evaluate as there were warm. There seemed to be a lack of definite association with many of the items. This group reported that it was much easier to decide on warm than on cool evaluations. The fact that the classes of objects regarded as cool, and those colors regarded as cool, occupy much the same relatively long range of hues, harmonizes with the associational view. Thus there may be no coolest color because there is no coolest common object(s) of unique color.

Sample 9G (500 mμ). This particular sample is unique in that it was scarcely ever (only twice) referred to throughout all the observations. The other 49 samples were referred to a number of times. Even in the case of the 537 hue assignments to objects indicated in Figure 4, sample 9G was selected only once. Therefore, the reason for the "athermality" of this sample may reside in an extraordinary lack of associable thermal objects.

Associational Hypothesis. The resemblances in the distributions of the thermal judgments of colors and the assigned colors of thermal objects leave little room for doubt that the external requirements for associative conditioning are normally present. While we cannot be sure that these resemblances represent the consequences of ontogenetic factors only, the general conclusion of some form of color-temperature association seems inevitable.

Summary

Within the experimental limitations, several generalizations seem indicated.

1. The reds and yellow reds are the thermally 'warmest' hues.
2. The cool hues range from yellow through green and blue to purple with no unequivocal 'coolest' mode. This result confirms the reality of the artist's difficulty which instigated this study.
3. The above results seem to be essentially independent of both sex and race.
4. The apparently warm and cool colors and the perceptually warm and cool objects, reported by the subjects as associated with them, are distributed in similar fashion.
5. The preceding result supports the plausible view that the

apparent warmth and coolness of colors depends upon bimodal reception from common chromatic sources of temperature stimulation.

6. The striking disagreement regarding a particular 'coolest' hue may depend upon an equivocal associational influence of the wide hue-range of commonly recognized cool objects.

7. There is overlapping of the warm and cool colors in the yellow and the purple blue regions, and this overlapping may be due in part to conflicting associations.

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